Chapter 3
Calculating the WQCV and Runoff Reduction

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1.0   Introduction

This chapter presents the hydrologic basis and calculations for the Water Quality Capture Volume (WQCV) and discusses the benefits of attenuating this volume and that of the Excess Urban Runoff Volume (EURV).   This chapter also describes various methods for quantifying runoff reduction when using LID practices. Use of these methods should begin during the planning phase for preliminary sizing and development of the site layout. The calculations and procedures in this chapter allow the engineer to determine effective impervious area, calculate the WQCV, and more accurately quantify potential runoff reduction benefits of BMPs.

2.0   Hydrologic Basis of the WQCV

2.1   Development of the WQCV

The purpose of designing BMPs based on the WQCV is to improve runoff water quality and reduce hydromodification and the associated impacts on receiving waters Although some BMPs can remove pollutants and achieve modest reductions in runoff for frequently occurring events in a "flow through" mode (e.g., grass swales, grass buffers or wetland channels), to address hydrologic effects of urbanization, a BMP must be designed to control runoff, either through storage, infiltration, evapotranspiration or a combination of these processes (e.g., rain gardens, extended detention basins or other storage-based BMPs). This section provides a brief background on the development of the WQCV.

The WQCV for the metro Denver area is based on an analysis of rainfall and runoff characteristics for 36 years of record at the Denver Stapleton Rain Gage (1948-1984) conducted by Urbonas, Guo, and Tucker (1989) and documented in *Sizing a Capture Volume for Stormwater Quality Enhancement* (available at the UDFCD website.) This analysis showed that the average storm for the Denver area, based on a 6-hour separation period, has duration of 11 hours and an average time interval between storms of 11.5 days. However, the great majority of storms are less than 11 hours in duration (i.e., median duration is less than average duration). The average is skewed by a small number of storms with long durations.

Table 3-1 summarizes the relationship between total storm depth and the annual number of storms. As the table shows, 61% of the 75 storm events that occur on an average annual basis have less than 0.1 inches of precipitation. These storms produce practically no runoff and therefore have little influence in the development of the WQCV. Storm events between 0.1 and 0.5 inches produce runoff and account for 76% of the remaining storm events (22 of the 29 events that would typically produce runoff on an average annual basis). Urbonas et al. (1989) identified the runoff produced from a precipitation event of 0.6 inches as the target for the WQCV, corresponding to the 80th percentile storm event. The WQCV for a given watershed will vary depending on the imperviousness and the drain time of the BMP, but assuming 0.1 inches of depression storage for impervious areas, the maximum capture volume required is approximately 0.5 inches over the area of the watershed. Urbonas et al. (1989) concluded that if the volume of runoff produced from impervious areas from these storms can be effectively treated and detained, water quality can be significantly improved.

For application of this concept at a national level, analysis by Driscoll et al. (1989), as shown in Figure 3-1, regarding average runoff producing events in the U.S. can be used to adjust the WQCV.

Table 3-1. Number of Rainfall Events in the Denver Area
(Adapted from Urbonas et al. 1989)

Total Rainfall Depth (inches)			Average Annual Number of Storm Events	Percent of Total Storm Events	Percentile of Runoff-producing Storms
0.0	to	0.1	46	61.07%	0.00%
0.1	to	0.5	22	29.21%	75.04%
	≤	**0.6**	**69**	**91.61%**	**80.00%**
0.5	to	1.0	4.7	6.24%	91.07%
1.0	to	1.5	1.5	1.99%	96.19%
1.5	to	2.0	0.6	0.80%	98.23%
2.0	to	3.0	0.3	0.40%	99.26%
3.0	to	4.0	0.19	0.25%	99.90%
4.0	to	5.0	0.028	0.04%	100.00%
	>	5.0	0	0.00%	100.00%
TOTAL:			**75**	**100%**	**100%**
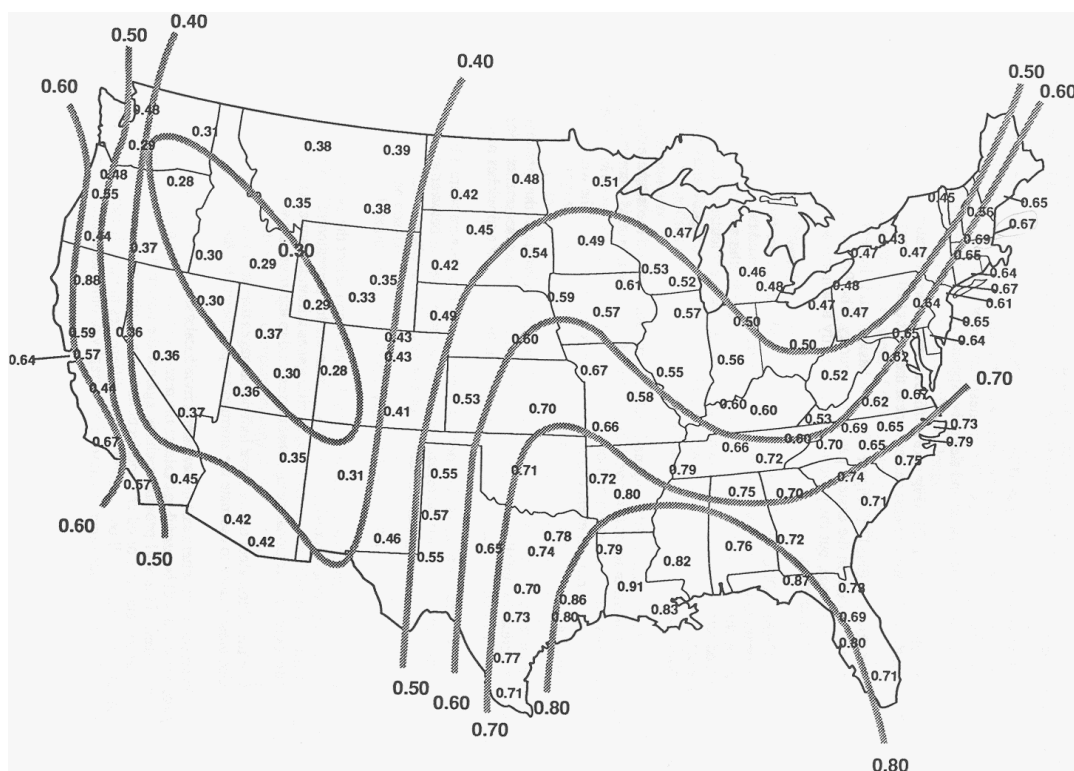
Figure 3-1. Map of the Average Runoff Producing Storm's Precipitation Depth in the United States In Inches
(Source: Driscoll et.al., 1989)

Based on rainfall data collected in the Fountain Creek watershed as described the Fountain Creek Rainfall Characterization Study (Carlton, 2011) a similar analysis was completed. This analysis showed that the rainfall patterns associated with small, frequent events in the Fountain Creek watershed are very similar to those in the metro Denver area. Therefore, **the requirements for WQCV used in metro Denver can be applied within the Fountain Creek watershed.** The analysis and its results are described in a memorandum by WWE (May, 2012).

2.2   Optimizing the Capture Volume

Optimizing the capture volume is critical. If the capture volume is too small, the effectiveness of the BMP will be reduced due to the frequency of storms exceeding the capacity of the facility and allowing some volume of runoff to bypass treatment. On the other hand, if the capture volume for a BMP that provides treatment through sedimentation is too large, the smaller runoff events may pass too quickly through the facility, without the residence time needed to provide treatment.

Small, frequently occurring storms account for the predominant number of events that result in stormwater runoff from urban catchments. Consequently, these frequent storms also account for a significant portion of the annual pollutant loads. Capture and treatment of the stormwater from these small and frequently occurring storms is required to satisfy the City's MS4 Permit conditions.

The analysis of precipitation data at the Denver Stapleton Rain Gage revealed a relationship between the percent imperviousness of a watershed and the capture volume needed to significantly reduce stormwater pollutants (Urbonas, Guo, and Tucker, 1990). Subsequent studies (Guo and Urbonas, 1996 and Urbonas, Roesner, and Guo, 1996) of precipitation resulted in a recommendation by the Water Environment Federation and American Society of Civil Engineers (1998) that stormwater quality treatment facilities (i.e., post-construction BMPs) be based on the capture and treatment of runoff from storms ranging in size from "mean" to "maximized[1]" storms. The "mean" and "maximized" storm events represent the 70th and 90th percentile storms, respectively. As a result of these studies, water quality facilities for the Colorado Front Range are recommended to capture and treat the 80th percentile runoff event. Capturing and properly treating this volume should remove between 80 and 90% of the annual TSS load, while doubling the capture volume was estimated to increase the removal rate by only 1 to 2%.

2.3   Attenuation of the WQCV (BMP Drain Time)

The WQCV must be released over an extended period to provide effective pollutant removal for post-construction BMPs that use sedimentation (i.e., extended detention basin, retention ponds and constructed wetland ponds). A field study of basins with extended detention in the Washington, D.C. area identified an average drain time of 24 hours to be effective for extended detention basins. This generally equates to a 40-hour drain time for the brim-full basin. Retention ponds and constructed wetland basins have reduced drain times (12 hours and 24 hours, respectively) because the hydraulic residence time of the effluent is essentially increased due to the mixing of the inflow with the permanent pool.

When pollutant removal is achieved primarily through filtration, such as in a sand filter or rain garden BMP, an extended drain time is required to promote stability of downstream drainageways. In addition to counteracting hydromodification, attenuation in filtering BMPs can also improve pollutant removal by increasing contact time, which can aid adsorption/absorption processes depending on the media. The

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[1] The term "maximized storm" refers to the optimization of the storage volume of a BMP. The WQCV for the "maximized" storm represents the point of diminishing returns in terms of the number of storm events and volume of runoff fully treated versus the storage volume provided.

minimum required drain time for a post-construction BMP is 12 hours for BMPs that do not rely fully or partially on sedimentation for pollutant removal.

2.4   Excess Urban Runoff Volume (EURV) and Full Spectrum Detention

Capture and treatment of the EURV is required as part of the Full Spectrum Detention criteria that is required in accordance with Chapter 3 – Drainage Policies in Volume 1. The EURV represents the difference between the developed and pre-developed runoff volume for the range of storms that produce runoff from pervious land surfaces (generally greater than the 2-year event). The EURV is relatively constant for a given imperviousness over a wide range of storm events. This is a companion concept to the WQCV. The EURV is a greater volume than the WQCV and is detained over a longer time. It typically allows for the recommended drain time of the WQCV and is used to better replicate peak discharge in receiving waters for runoff events exceeding the WQCV. The EURV is associated with Full Spectrum Detention, a simplified sizing method for both water quality and flood control detention. Designing a detention basin to capture the EURV and release it slowly (at a rate similar to WQCV release rates) results in storms smaller than the 2-year event being reduced to flow rates much less than the threshold value for erosion in most drainageways. In addition, by incorporating an outlet structure designed per the criteria in this manual including an orifice or weir that limits 100-year runoff to the allowable release rate, the storms greater than the 2-year event will be reduced to discharge rates and hydrograph shapes that approximate pre-developed conditions. This reduces the likelihood that runoff hydrographs from multiple basins will combine to produce greater peak discharges than pre-developed conditions.

For the EURV and Full Spectrum Detention criteria and requirements, including calculation procedures, please refer to the *Storage* chapter of Volume 1.

3.0   Calculation of the WQCV

The first step in estimating the magnitude of runoff from a site is to estimate the site's total imperviousness. The total imperviousness of a site is the weighted average of individual areas of like imperviousness. For instance, according to the *Hydrology* chapter of Volume 1 of this manual, paved streets (and parking lots) have an imperviousness of 100%; drives, walks and roofs have an imperviousness of 90%; and lawn areas have an imperviousness of 0%. The total imperviousness of a site can be determined taking an area-weighted average of all of the impervious and pervious areas. These impervious areas are assumed to be directly connected to the receiving systems beyond the site. When measures are implemented to minimize directly connected impervious area (MDCIA), the effects of the total imperviousness on the calculated WQCV can be represented by using an "effective imperviousness". Sections 4 and 5 of this chapter provide guidance, requirements, and examples for calculating effective imperviousness and adjusting the WQCV using this value.

The WQCV is calculated as a function of imperviousness and BMP drain time using Equation 3-1, and as shown in **Figure 3-2**:

$$\text{WQCV} = a(0.91I^3 - 1.19I^2 + 0.78I) \hspace{3cm} \text{Equation 3-1}$$

Where:

WQCV   = Water Quality Capture Volume (watershed inches)

$\quad a$ = Coefficient corresponding to WQCV drain time (Table 3-2)

I = Imperviousness (%)

Table 3-2. Drain Time Coefficients for WQCV Calculations

Drain Time (hrs)	Coefficient, a
12 hours	0.8
24 hours	0.9
40 hours	1.0

Figure 3-2, which illustrates the relationship between imperviousness and WQCV for various drain times, is appropriate for use in Colorado's high plains near the foothills. For other portions of Colorado or United States, the WQCV obtained from this figure can be adjusted using the following relationships:

$$\text{WQCV}_{\text{other}} = d_6 \left(\frac{\text{WQCV}}{0.43} \right)$$
<div align="right">Equation 3-2</div>

Where:

WQCV   = WQCV calculated using Equation 3-1 or **Figure 3-2**   (watershed inches)

$\text{WQCV}_{\text{other}}$ = WQCV outside of Denver region (watershed inches)

d_6 = depth of average runoff producing storm from Figure 3-1 (watershed inches)

Once the WQCV in watershed inches is found from **Figure 3-2** or using Equation 3-1 and/or 3-2, the required BMP storage volume in acre-feet can be calculated as follows:
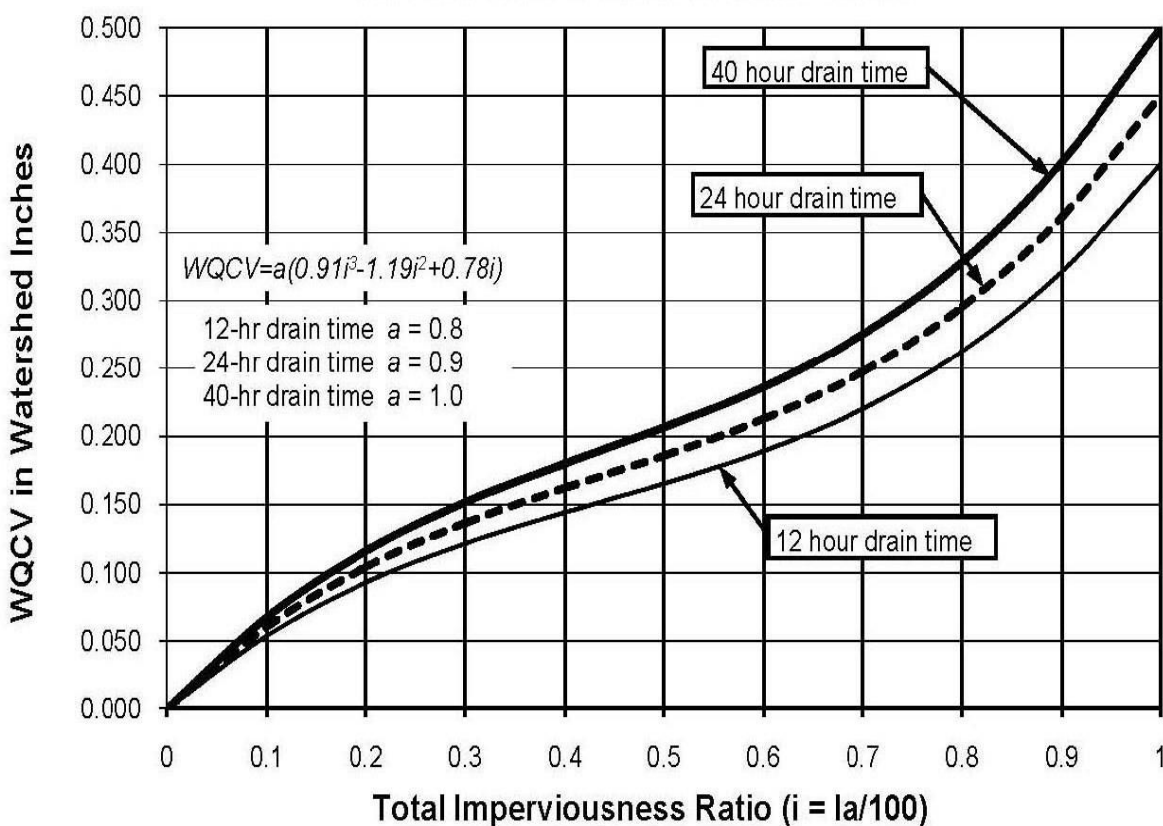
$$V = \left(\frac{\text{WQCV}}{12} \right) A$$
<div align="right">Equation 3-3</div>

Where:

V = required storage volume (acre-ft)

A = tributary catchment area upstream (acres)

WQCV   = Water Quality Capture Volume (watershed inches)

Figure 3-2. Water Quality Capture Volume (WQCV) Based on BMP Drain Time

4.0   Quantifying Runoff Reduction

Runoff reduction is an important part of the Four Step Process and is fundamental to effective stormwater management. Quantifying runoff reduction associated with MDCIA, LID practices and other BMPs is important for watershed-level master planning and also for conceptual and final site design. It also allows the engineer to evaluate and compare the benefits of various runoff reduction practices. This section describes the conceptual model for evaluating runoff reduction and provides tools for quantifying runoff reduction using three different approaches, depending on the size of the watershed, complexity of the design, and experience level of the user. In this section, runoff reduction is evaluated at the watershed level and at the site level.

4.1   Conceptual Model for Runoff Reduction BMPs—Cascading Planes

The hydrologic response of a watershed during a storm event is characterized by factors including shape, slope, area, imperviousness (connected and disconnected) and other factors (Guo 2006). As previously discussed, total imperviousness of a watershed can be determined by delineating roofs, drives, walks and other impervious areas within a watershed and dividing the sum of these impervious areas by the total watershed area. In the past, total imperviousness was often used for calculation of peak flow rates for design events and storage requirements for water quality and flood control purposes. This is a reasonable approach when much of the impervious area in a watershed is directly connected to the drainage system; however, when the unconnected impervious area in a catchment is significant, using total imperviousness will result in over-calculation of peak flow rates and storage requirements.

To evaluate the effects of MDCIA and other LID practices, UDFCD has performed modeling using SWMM to develop tools for planners and designers, both at the watershed/master planning level where site-specific details have not been well defined, and at the site level, where plans are at more advanced stages. Unlike many conventional stormwater models, SWMM allows for a relatively complex evaluation of flow paths through the on-site stormwater BMP layout. Conceptually, an urban watershed can be divided into four land use areas that drain to the common outfall point as shown in Figure 3-3, including:

Directly Connected Impervious Area (DCIA)

Unconnected Impervious Area (UIA)

Receiving Pervious Area (RPA)

Separate Pervious Area (SPA)

> **Defining Effective Imperviousness**
>
> The concepts discussed in this section are dependent on the concept of *effective imperviousness*. This term refers to impervious areas that contribute surface runoff to the drainage system. For the purposes of this manual, effective imperviousness includes directly connected impervious area and portions of the unconnected impervious area that also contribute to runoff from a site. For small, frequently occurring events, the effective imperviousness may be equivalent to directly connected impervious area since runoff from unconnected impervious areas may infiltrate into receiving pervious areas; however, for larger events, the effective imperviousness is increased to account for runoff from unconnected impervious areas that exceeds the infiltration capacity of the receiving pervious area. This means that the calculation of effective imperviousness is associated with a specific return period.
>
> Note: Users should be aware that some national engineering literature defines *effective imperviousness* more narrowly to include only directly connected impervious area.
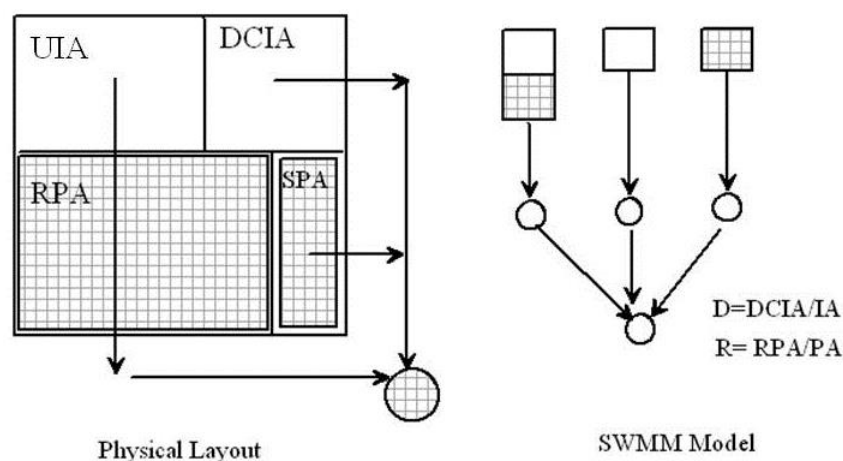
Figure 3- 3. Four Component Land Use

A fundamental concept of LID is to route runoff generated from the UIA onto the RPA to increase infiltration losses. To model the stormwater flows through a LID site, it is necessary to link flows similarly to take into consideration additional depression storage and infiltration losses over the pervious landscape. One of the more recent upgrades to SWMM allows users to model overland flow draining from the upper impervious areas onto a downstream pervious area. As illustrated in Figure 3-3, the effective imperviousness is only associated with the cascading plane from UIA to RPA, while the other two areas, DCIA and SPA, are drained independently.

For a well-designed and properly constructed LID site, the effective imperviousness will be less than the total imperviousness. This difference will be greatest for smaller, more frequently occurring events and less for larger, less-frequent events. Aided by SWMM, effective imperviousness can be determined by a runoff-volume weighting method that accounts for losses along the selected flow paths. When designing a drainage system, design criteria that account for effective imperviousness can potentially reduce stormwater costs by reducing the size of infrastructure to convey and/or store the design stormwater flows and volumes. This chapter presents methods that allow the engineer to convert between total imperviousness and effective imperviousness at both the watershed and site scales.

## 4.2   Watershed/Master Planning-level Runoff Reduction Method

For watershed-level assessments and master planning, NRCS (TR-55) provides guidance for users to model effects of LID through adjustments to Curve Number for unconnected imperviousness.

Figure 3-4 can be used to estimate composite CNs for unconnected impervious areas. Runoff from these areas is spread over a pervious area as sheet flow. To determine CN when all or part of the impervious area is not directly connected to the drainage system, Figure 3-4 may be used if total imperviousness is less than 30 percent. Otherwise the methods for estimating effective imperviousness described elsewhere in this chapter may be used to estimate composite CNs.

Obtain the composite CN for unconnected impervious areas by entering the right half of Figure 3-4 with the percentage of total impervious area and the ratio of total unconnected impervious area to total impervious area. Then move left to the appropriate pervious CN and read down to find the composite CN. For example, for a 1.2 acre lot with 20 percent total impervious area (75 percent of which is unconnected) and pervious CN of 60, the composite CN from Figure 3-4 is 64. If all of the impervious area is connected, the composite CN would be 68. Figure 3-4 is intended for use at the planning level

when specifics of the site conditions are not yet well established.

It is notable that the reductions in effective imperviousness shown in Figure 3-4 are relatively modest. When site-level details are still in conceptual stages, the use of effective impervious calculations and composite unconnected CNs provides a tool for a master planning/watershed level assessment of effects of disconnected impervious area. At a more advanced stage of design, when site-specific disconnected areas, receiving pervious areas, flow paths, and other design details are available, the site-level methods in Section 4.3 can be used to better quantify runoff reduction, and results will typically show greater reductions in effective imperviousness for aggressive LID implementation than reflected in Figure 3-4. Even so, to ensure compliance with the City's requirement to capture and treat the EURV, it is unlikely that conveyance-based BMPs alone will provide adequate pollutant removal and runoff reduction for most project sites, and a storage-based BMP will also be required.
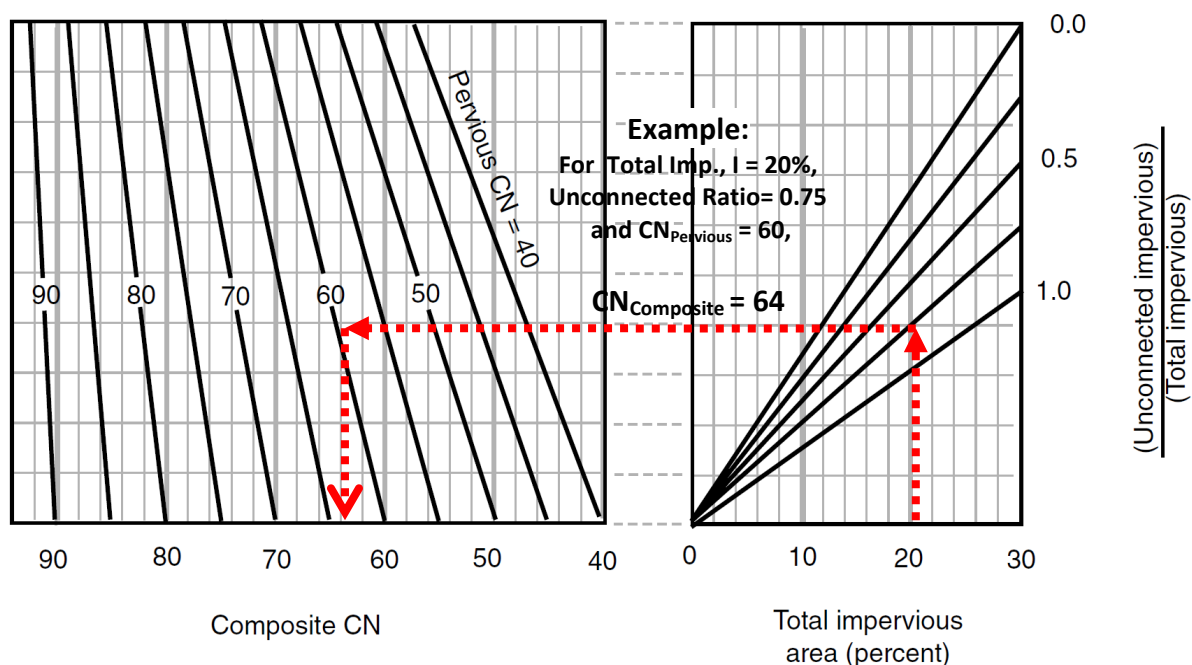
Figure 3-4. Composite Curve Number with Unconnected Imperviousness
(Source: TR-55, Figure 2-4)

4.3   Site-level Runoff Reduction Methods

Two options are available for quantification of runoff reduction at the site level when the DCIA, UIA, RPA, and SPA fractions have been identified:

1. SWMM modeling using the cascading plane approach (must use Horton or Green Ampt for infiltration;the CN method in EPA SWMM may produce different results than the NRCS CN method), or

2. UDFCD Imperviousness Reduction Factor (IRF) charts and spreadsheet (located within the *UD-BMP* workbook available at the UDFCD website)

The UDFCD IRF charts and spreadsheet were developed using a dimensionless SWMM modeling

approach developed by Guo et al. (2010) that determines the effective imperviousness of a site based on the total area-weighted imperviousness and the ratio of the infiltration rate (average infiltration rate based on Green-Ampt), *f*, to the rainfall intensity, *I*. Because the IRF is based on cascading plane SWMM modeling, it will yield results that are generally consistent with creation of a site-specific SWMM model.

To apply either of the above methods, a project site must first be divided into sub-watersheds based on topography and drainage patterns. For each sub-watershed, the areas of DCIA, UIA, RPA and SPA are calculated. Sub-watersheds (and associated BMPs) will fall into one of two categories based on the types of BMPs used:

1. **Conveyance-based:** Conveyance-based BMPs include grass swales, vegetated buffers, and disconnection of roof drains and other impervious areas to drain to pervious areas (UDFCD 1999a). Conveyance based BMPs may have some incidental, short-term storage in the form of channel storage or shallow ponding, but do not provide the WQCV, EURV or flood-control detention volume.

2. **Storage-based:** Storage-based BMPs include rain gardens, permeable pavement systems as detailed in this manual, extended detention basins and other BMPs in this manual that provide the WQCV, EURV or flood control detention volume.

4.3.1   SWMM Modeling Using Cascading Planes

Because of complexities of modeling LID and other BMPs using SWMM, the cascading planes alternative for site-level runoff reduction analysis is <u>recommended only for experienced users</u>. Guidance for conveyance- and storage-based modeling includes these steps:

1. Each sub-watershed should be conceptualized as shown in Figure 3-3. Two approaches can be used in SWMM to achieve this:

   ▪ Create two SWMM sub-catchments for each sub-watershed, one with UIA 100% routed to RPA and the other with DCIA and SPA independently routed to the outlet, or

   ▪ Use a single SWMM sub-catchment to represent the sub-watershed and use the SWMM internal routing option to differentiate between DCIA and UIA. This option should only be used when a large portion of the pervious area on a site is RPA and there is very little SPA since the internal routing does not have the ability to differentiate between SPA and RPA (i.e., the UIA is routed to the entire pervious area, potentially overestimating infiltration losses).

2. Once the subwatershed is set up to represent UIA, DCIA, RPA and SPA in SWMM, the rainfall distribution should be directly input to SWMM.

3. Parameters for infiltration, depression storage and other input parameters should be selected in accordance with the guidance in the *Hydrology* chapter of Volume 1.

4. For storage-based BMPs, there are two options for representing the WQCV:

   ▪ The pervious area depression storage value for the RPA can be increased to represent the WQCV. This approach is generally applicable to storage-based BMPs that promote infiltration such as rain gardens, permeable pavement systems with storage or sand filters. This adjustment should not be used when a storage-based BMP has a well-defined outlet and a stage-storage-discharge relationship that can be entered into SWMM.

- The WQCV can be modeled as a storage unit with an outlet in SWMM. This option is preferred for storage-based BMPs with well defined stage-storage-discharge relationships such as extended detention basins.

These guidelines are applicable for EPA SWMM Version 5.0.018 and earlier versions going back to EPA SWMM 5.0. EPA has developed SWMM Version 5.0.0.022 with enhanced LID modeling capabilities; however, this version had not been fully vetted at the time this manual was released and should be applied with caution.

4.3.2   IRF (K) Charts and Spreadsheet

When UIA, DCIA, RPA, SPA and WQCV, if any, for a site have been defined, this method provides a relatively simple procedure for calculating effective imperviousness and runoff reduction. Fundamentally, the IRF charts and spreadsheet are based on the following relationships.

For a conveyance-based approach:

$$K = \text{Fct}\left(\frac{F_d}{P}, A_r\right) = \left(\text{Fct}\frac{f}{I}, A_r\right)$$

For a storage-based approach:

$$K = \text{Fct}\left(\frac{F_d}{P}, A_r, A_d\frac{\text{WQCV}}{P}\right)$$

Where Fct designates a functional relationship and:

K = IRF (effective imperviousness/total imperviousness)

F_d = pervious area infiltration loss (in)

P = design rainfall depth (in)

A_r = RPA/UIA

f = pervious area average infiltration rate (in/hr)

I = rainfall intensity (in/hr)

A_d = RPA

WQCV = Water Quality Capture Volume (watershed inches)

A full derivation of equations based on these functional relationships can be found in Guo et al. (2010). The results of cascading plane modeling based on these relationships is shown in Figure 3-5 for the conveyance-based approach and Figure 3-6 for the storage-based approach.

Table 3-3 provides average infiltration rates that should be used for IRF calculations as a function of soil type and drain time.

Table 3-3. Infiltration Rates (*f*) for IRF Calculations

Soil Type	Conveyance-based[1]	Storage-based		
		12-hours	24-hours	40-hours
	(in/hr)	(in/hr)	(in/hr)	(in/hr)
Sand	5.85	5.04	4.91	4.85
Loamy Sand	1.92	1.40	1.31	1.27
Sandy Loam	1.04	0.64	0.56	0.52
Silt Loam	0.83	0.46	0.39	0.35
Loam	0.43	0.24	0.20	0.18
Sandy Clay Loam	0.34	0.16	0.13	0.11
Silty Clay Loam	0.27	0.13	0.10	0.08
Clay Loam	0.26	0.13	0.10	0.08
Silty Clay	0.18	0.08	0.06	0.05
Sandy Clay	0.16	0.08	0.06	0.05
Clay	0.12	0.05	0.04	0.03

[1] Values for conveyance-based BMPs are based on a 2-hour duration.

When using Figure 3-5 and Figure 3-6, it is important to understand that the curves are based on ratios of infiltration and precipitation *rates*, not depths. Therefore the f/I = 2.0 curve could represent soils with an average infiltration rate of 1 inch per hour and an event with a total precipitation of 0.5 inches in 1 hour (i.e., an event with a total depth that is roughly the same as the WQCV) or a longer event, such as 2.0 inches over 4 hours, which still would have a rainfall intensity of 0.5 inches per hour but that would have a total precipitation depth and overall runoff volume greater than the WQCV. Therefore, when using the storage-based curves in Figure 3-6 for small events, it is important to check the total precipitation depth as well as the f/I ratio. In cases where the total precipitation depth is less than 0.6 inches and the full WQCV is provided, the IRF, represented as *K*, can be set to 0 because all of the runoff will be captured by the storage-based BMP and released over an extended period, having minimal downstream effect on the timescale of an event. The *UD-BMP* worksheet approximates one-hour precipitation intensity as the one hour point precipitation depth and performs a check of the precipitation depth relative to the WQCV, assigning *K* = 0, when the precipitation depth is less than the WQCV for storage-based BMPs.

Once *K* is known for a given storm event, the following equation can be used to calculate the effective imperviousness for that event:

$$I_{\text{Effective}}(\%) = \left(\frac{\text{DCIA} + (K \cdot \text{UIA})}{\text{DCIA} + \text{UIA} + \text{RPA} + \text{SPA}}\right) \cdot 100 \qquad \text{Equation 3-4}$$

Where:

    DCIA   = directly connected impervious area

    UIA   = unconnected impervious area

    RPA   = receiving pervious area
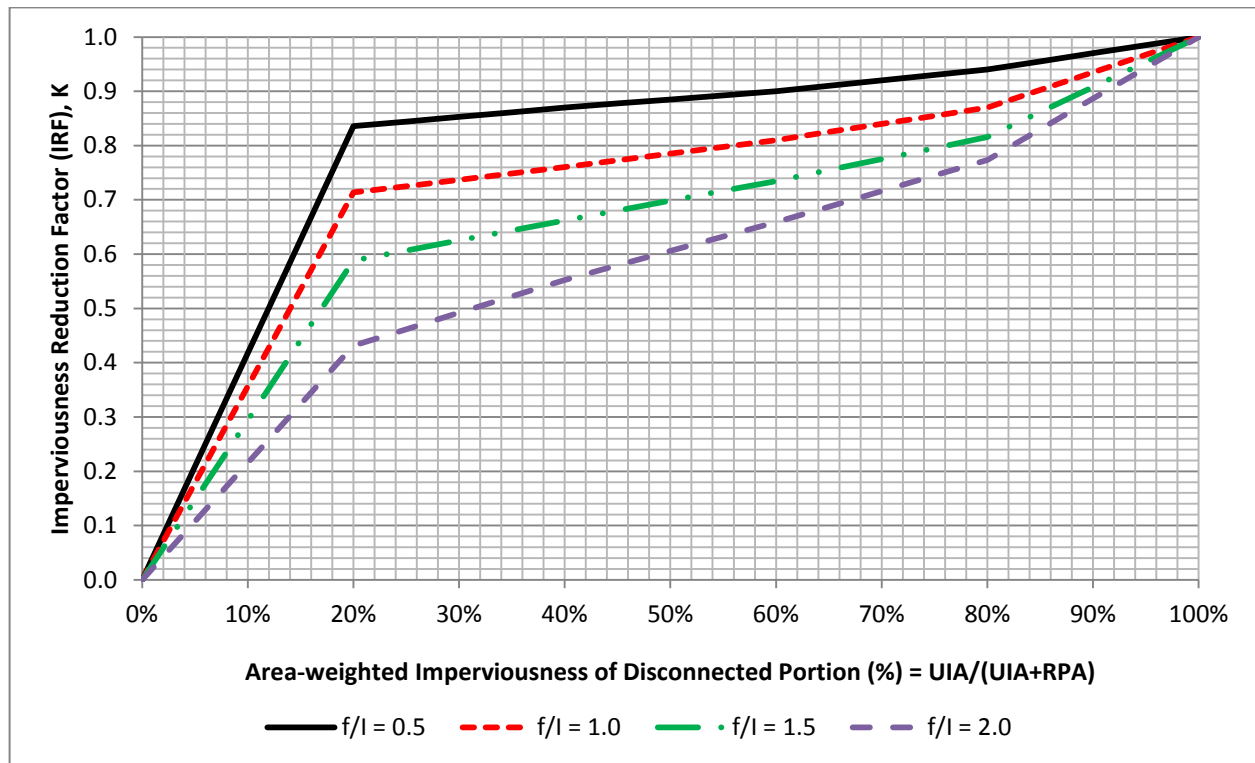
    SPA   = separate pervious area

Figure 3-5. Conveyance-based Imperviousness Reduction Factor

Note: When the total depth of the storm event is less than the WQCV and the full WQCV is provided for a sub-basin, K = 0.
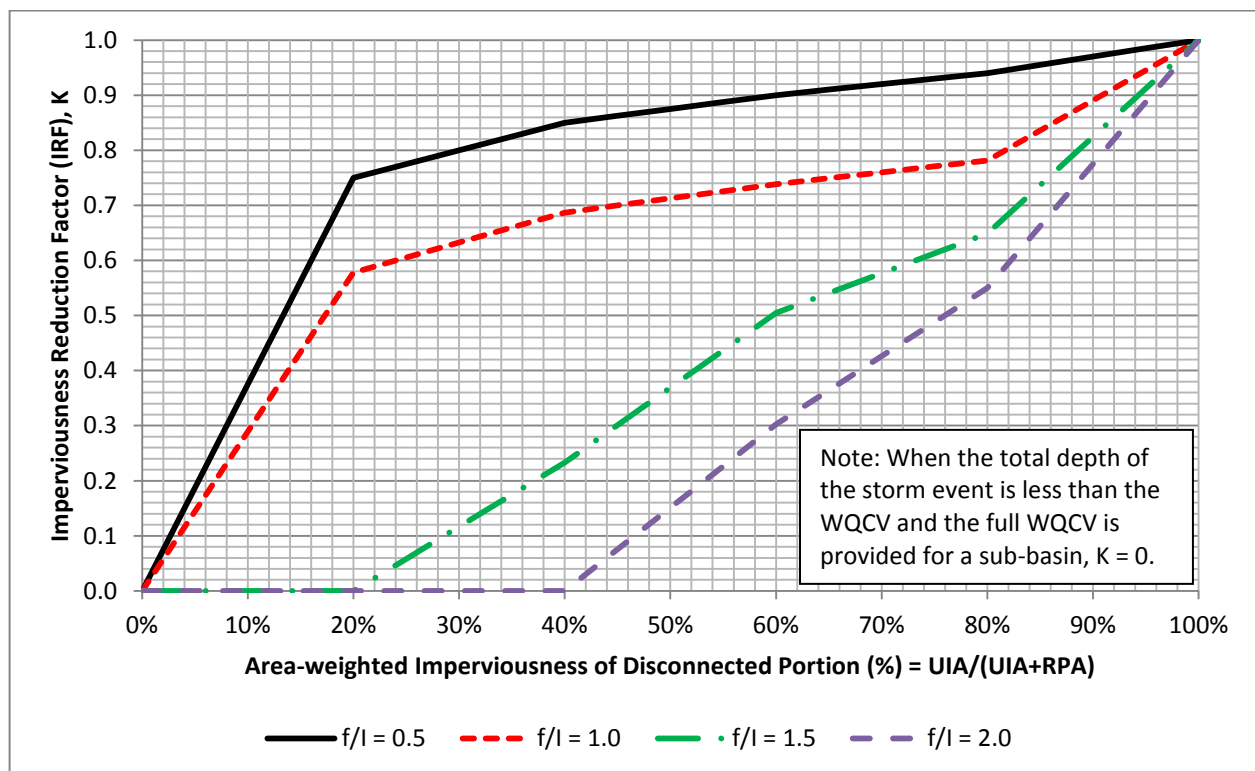
Figure 3-6. Storage-based Imperviousness Reduction Factor

Four basic steps can be used to determine effective imperviousness when parameters including UIA, DCIA, RPA, SPA, WQCV, *f* and *I* are known. For clarity, these steps are accompanied by an example using a sub-watershed with a conveyance-based approach (i.e., no WQCV) with UIA = 0.25 acres, DCIA = 0.25 acres, RPA = 0.25 acres, SPA = 0.25 acres, *f* = 1.0 inch/hour and *I* = 0.5 inch/hour.

1. Calculate the area-weighted imperviousness of the disconnected portion. The disconnected portion of the sub-watershed consists of the UIA and the RPA. The area weighted imperviousness is calculated as UIA/(UIA+RPA).

    For the example, UIA + RPA = 0.25 + 0.25 = 0.50 acres. The area-weighted imperviousness of this area = 0.25/0.50 = 0.50 or 50%.

2. Calculate f/I based on the rainfall intensity for the design storm and the infiltration rate for the given RPA soil type. In this example, the 1-hour intensity is given as 0.5 inch/hour in the problem statement, and the infiltration rate is specified as 1 inch/hour. For this example, based on Table 3-3, the 1.0 inch/hour infiltration rate specified in the problem statement would roughly correspond to a sandy loam soil type for a conveyance-based BMP.

    For the example, *f/I* = 1.0/0.5 = 2.0.

    For simplicity, the 1-hour rainfall intensity can be approximated as the 1-hour point precipitation depth for a given frequency. The 1-hour point precipitation values can be determined from information provided in the *Hydrology* chapter of Volume 1.

3. Using the appropriate figure (Figure 3-5 for the conveyance-based approach or Figure 3-6 for the storage-based approach), determine the Imperviousness Reduction Factor, *K*, corresponding to where the appropriate *f/I* line would be intersected by the x-axis value for area-weighted imperviousness. **Note: Figure 3-6 for the storage-based approach should only be used if the full WQCV is provided for the sub-watershed**. If quantification of volume reduction benefits of only a fraction of the WQCV (one-half for example) is required, Figure 3-6 is not applicable and SWMM modeling will be required.

    For the example, the *K* value corresponding to *f/I* = 2.0 and an area-weighted imperviousness of 50% using the conveyance-based chart, Figure 3-5, is 0.60. **It is very important to note that this *K* value applies only to the disconnected portion of the sub-watershed (i.e., UIA + RPA).**

4. Calculate the effective imperviousness of the sub-watershed. This calculation must factor in both connected and disconnected portions of the site:

    $$I_{\text{Effective}}(\%) = \left(\frac{\text{DCIA} + (K \cdot \text{UIA})}{\text{DCIA} + \text{UIA} + \text{RPA} + \text{SPA}} \right) \cdot 100$$

    For the example, with DCIA = UIA = RPA = SPA = 0.25 acres and *K* = 0.60:

    $$I_{\text{Effective}}(\%) = \left(\frac{0.25 + (0.60 \cdot 0.25)}{0.25 + 0.25 + 0.25 + 0.25} \right) \cdot 100 = 40\%$$

    This can be compared to the total area-weighted imperviousness for the sub-watershed = (DCIA + UIA)/ (DCIA + UIA + RPA + SPA) × 100% = 50%.

    To calculate runoff reduction benefits associated with conveyance- or storage-based approaches, the

effective imperviousness values determined according to this procedure (or using the spreadsheet tool *UD-BMP*) can be used in WQCV calculations and detention storage equations, such as the empirical storage equations in the *Storage* chapter of Volume 1. The WQCV and detention volume requirements calculated using the effective imperviousness can be compared with the same calculations using total sub-watershed imperviousness to determine potential volume reductions.

Section 5.2 provides an example of the storage-based approach to complement the conveyance-based example above, as well as guidance for using the spreadsheet tool.

5.0   Examples

5.1   Calculation of WQCV

Calculate the WQCV for a 1.0-acre sub-watershed with a total area-weighted imperviousness of 50% that drains to a rain garden (surface area of the rain garden is included in the 1.0 acre area):

Determine the appropriate drain time for the type of BMP. For a rain garden, the required drain time is 12 hours. The corresponding coefficient, *a*, from

1. Table 3-2 is 0.8.

2. Either calculate or use **Figure 3-2** to find the WQCV based on the drain time of 12 hours ($a = 0.8$) and total imperviousness = 50% ($I = 0.50$ in Equation 3-1):

$$WQCV = 0.8(0.91(0.50)^3 - 1.19(0.50)^2 + 0.78(0.50))$$

$$WQCV = 0.17 \text{ watershed inches}$$

3. Calculate the WQCV in cubic feet using the total area of the sub-watershed and appropriate unit conversions:

$$WQCV = (0.17 \text{ w.s. in.})(1 \text{ ac})\left(\frac{1\text{ft}}{12 \text{ in}}\right)\left(\frac{43560 \text{ ft}^2}{1 \text{ ac}}\right) \approx 600 \text{ ft}^3$$

Although this example calculated the WQCV using total area-weighted imperviousness, the same calculation can be repeated using effective imperviousness if LID BMPs are implemented to reduce runoff volume.

5.2   Runoff Reduction Calculations for Storage-based Approach

Determine the effective imperviousness for a 1-acre sub-watershed with a total imperviousness of 50% that is served by a rain garden (storage-based BMP) for the water quality and 10-year events. Assume that the pervious area is equally-split between RPA and SPA with 0.25 acres for each and that the RPA is a rain garden with a sandy loam soil. Because a rain garden provides the WQCV, the curves for the storage-based approach can be used with UIA = 0.50 acres (1 acre · 50% impervious), RPA = 0.25 acres, SPA = 0.25 acres. There is no DCIA because everything drains to the rain garden in this example. To determine *f*, use Table 3-3 to look up the recommended infiltration rate for a sandy loam corresponding to a 12-hour drain time—the resulting infiltration rate is 0.64 inches/hour.

1. Calculate the area-weighted imperviousness of the disconnected portion. The disconnected portion of the sub-watershed consists of the UIA and the RPA. The area weighted imperviousness is calculated as UIA/(UIA+RPA).

For the example, UIA + RPA = 0.50 + 0.25 = 0.75 acres. The area-weighted imperviousness of this area = 0.50/0.75 = 0.67 or 67%.

2. Determine rainfall intensities for calculation of *f/I* ratios. For the water quality event, which is roughly an 80th percentile event, there is no specified duration, so assume rainfall intensity based on a 1-hour duration, giving an intensity of approximately 0.6 inches/hour. For the water quality event, this is generally a conservative assumption since the runoff that enters the rain garden will have a mean residence time in the facility of much more than 1 hour. For the 10-year event, the 1-hour point rainfall depth from the *Hydrology* chapter, Volume 1, can be used to approximate the rainfall intensity for calculation of the *f/I* ratio. For this example, the 1-hour point precipitation for the 10-year event is approximately 1.55 inches, equating to an intensity of 1.55 inches/hour.

3. Calculate *f/I* based on the design rainfall intensity (0.6 inches/hour) and RPA infiltration rate from Table 3-3 (0.64 inches/hour).

   For the water quality event, *f/I* = 0.64/0.6 = 1.07.

   For the 10-year event, *f/I* = 0.64/1.55 = 0.41.

4. Using the appropriate figure (Figure 3-6 for the storage-based approach in this case), determine the Imperviousness Reduction Factor *K*, corresponding to where the appropriate *f/I* line would be intersected by the x-axis value for area-weighted imperviousness.

   For the water quality event, the *K* value corresponding to *f/I* = 1.07 and an area-weighted imperviousness of 50% using the storage-based chart, Figure 3-6, would be approximately 0.64; however, because the total depth of the water quality event is provided as the WQCV for the storage-based rain garden, *K* is reduced to 0 for the water quality event.

   For the 10-year event, the *K* value corresponding to *f/I* = 0.41 and an area-weighted imperviousness of 50% using the storage-based chart, Figure 3-6, is approximately 0.94.

   It is very important to note that these *K* values apply only to the disconnected portion of the sub-watershed (i.e., UIA + RPA). If this example included DCIA, the total imperviousness would be higher.

5. Calculate the effective imperviousness of the sub-watershed. This calculation must factor in both connected and disconnected portions of the site:

$$I_{\text{Effective}} = \left(\frac{\text{DCIA} + (K \cdot \text{UIA})}{\text{DCIA} + \text{UIA} + \text{RPA} + \text{SPA}} \right) \cdot 100$$

For the water quality event, with DCIA = 0 acres, UIA = 0.5 acres and RPA = SPA = 0.25 acres, with *K* = 0:

$$I_{\text{Effective}} = \left(\frac{0.00 + (0.0 \cdot 0.5)}{0.0 + 0.5 + 0.25 + 0.25} \right) \cdot 100 = 0\%$$

For the 10-year event, with DCIA = 0 acres, UIA = 0.5 acres and RPA = SPA = 0.25 acres, with *K* = 0.94:

$$I_{\text{Effective}} = \left(\frac{0.00 + (0.94 \cdot 0.5)}{0.0 + 0.5 + 0.25 + 0.25} \right) \cdot 100 = 47\%$$

These effective imperviousness values for the sub-watershed (0% for the water quality event and 47% for the 10-year event) can be compared to the total area-weighted imperviousness of 50%. These values can be used for sizing of conveyance and detention facilities.

5.3   Effective Imperviousness Spreadsheet

Because most sites will consist of multiple sub-watersheds, some using the conveyance-based approach and others using the storage-based approach, a spreadsheet capable of applying both approaches to multiple sub-watersheds to determine overall site effective imperviousness and runoff reduction benefits is a useful tool. The *UD-BMP* workbook has this capability, and is required for use in calculations involving runoff reduction.

Spreadsheet inputs include the following for each sub-watershed:

Sub-watershed ID = Alphanumeric identifier for sub-watershed

Receiving Pervious Area Soil Type

Total Area (acres)

DCIA = directly connected impervious area (acres)

UIA = unconnected impervious area (acres)

RPA = receiving pervious area (acres)

SPA = separate pervious area (acres)

Infiltration rate, *f*, for RPA = RPA infiltration rate from Table 3-3 (based on soil type)

Sub-watershed type = conveyance-based "C" or volume-based "V"

Rainfall input = 1-hour point rainfall depths from the *Hydrology* chapter of Volume 1.

Calculated values include percentages of UIA, DCIA, RPA, and SPA; *f/I* values for design events; Imperviousness Reduction Factors (*K* values) for design events; effective imperviousness for design events for sub-watersheds and for the site as a whole; WQCV for total and effective imperviousness; and 10- and 100-year empirical detention storage volumes for total and effective imperviousness. Note that there may be slight differences in results between using the spreadsheet and the figures in this chapter due to interpolation to translate the figures into a format that can be more-easily implemented in the spreadsheet.

To demonstrate how the spreadsheet works, this section steps through two sub-basins from the Colorado Green development, shown in Figure 3-7. The Colorado Green development is a hypothetical LID development based on a real site plan. This example focuses on two sub-basins: (1) Sub-basin A which uses a volume-based approach and (2) Sub-basin E, which uses a conveyance-based LID approach. Note: For users working through this example using a calculator, to achieve results that closely agree with the spreadsheet entries, **do not** round interim results when used in subsequent equations.

Precipitation Input

Input data for precipitation include the following (see Figure 3-8).

1-hour point precipitation depth for the water quality event: The WQCV is relatively constant across the metropolitan Denver area and Fountain Creek watershed, and is set at 0.60 inches. There is no specified duration for the WQCV, so for purposes of conservatively estimating the 1-hour point rainfall depth, the spreadsheet input assumes that the WQCV total precipitation depth occurs over a period of one hour. The spreadsheet input value for the 1-hour point rainfall depth for the water quality event should not change from the value in the example spreadsheet as long as the project is in the metropolitan Denver area or Fountain Creek watershed.

10-year, 1-hour point rainfall depth: Determine the 10-year 1-hour point rainfall depths from Rainfall Depth-Duration-Frequency figures in the *Rainfall* chapter of Volume 1. For this example, the 10-year, 1-hour point rainfall depth is approximately 1.55 inches.

100-year, 1-hour point rainfall depth: Determine the 100-year 1-hour point rainfall depths from the *Hydrology* chapter of Volume 1. For this example, the 100-year, 1-hour point rainfall depth is approximately 2.52 inches.

Area and Infiltration Inputs

After precipitation data have been entered, the next step is to classify all areas of the site as UIA, RPA, DCIA, or SPA (see Figure 3-7) and to enter the areas into the spreadsheet in appropriate columns. Please note that blue bordered cells are designated for input, while black bordered cells are calculations performed by the spreadsheet. For the two sub-basins used in this example, A and E, inputs are:

Sub-basin A—DCIA = 0.00 ac, UIA = 0.56 ac, RPA =0.44 ac, SPA = 0.15 ac

Sub-basin E—DCIA = 0.00 ac, UIA = 0.11 ac, RPA =0.04 ac, SPA = 0.00 ac

The program calculates total area for each sub-basin as DCIA + UIA + RPA+ SPA and ensures that this value matches the user input value for total area:

Sub-basin A Total Area (ac) = 0.00 + 0.56 + 0.15 + 0.44 = 1.15 ac

Sub-basin E Total Area (ac) = 0.00 + 0.11 + 0.00 + 0.04 = 0.15 ac

The spreadsheet also calculates percentages of each of the types of areas by dividing the areas classified as DCIA, UIA, SPA and RPA by the total area of the sub-basin.

For each sub-basin, the user must enter the soil type and specify whether the RPA for each sub-basin is a conveyance-based ("C") or storage/volume-based ("V") BMP. The volume-based option should be selected only when the full WQCV is provided for the entire sub-basin. If the RPA is a volume-based BMP providing the full WQCV, the drain time must also be specified. Based on this input the spreadsheet will provide the infiltration rate. For sub-basins A and E in the example, the RPA is assumed to have sandy loam soils in the areas where BMPs will be installed. A rate of 0.64 inches per hour is used for Sub-basin A based on a sandy loam soil and a 12-hour drain time, and a rate of 1.04 inches/hour is used for Sub-basin E based on a sandy loam soil and a conveyance-based BMP type. Area and infiltration inputs are illustrated in Figure 3-9.

AR and f/I Calculations

After area and RPA infiltration parameters are input, the spreadsheet performs calculations of the A_R ratio and f/I parameters for design storm events including the water quality event and the 10- and 100-year events. Spreadsheet calculations are shown in Figure 3-10.

Calculations for **Sub-basin A** include the following:

$$A_R = \frac{RPA}{UIA} = \frac{0.44 \text{ ac}}{0.56 \text{ ac}} = 0.79$$

In general, the higher this ratio is, the greater the potential for infiltration and runoff reduction.

$$I_{a \text{ Check}} = \frac{1}{1 + A_R} = \frac{1}{1 + 0.79} = 0.56$$

This is mathematically equivalent to UIA/(RPA+UIA) = 0.56/(0.44+0.56).

Next the spreadsheet calculates f/I parameters using the RPA infiltration rate and the 1-hour maximum intensity values for each event (values in the spreadsheet are rounded to the tenths place). Values for Sub-basin A include:

$$\frac{f}{I_{WQ}} = \frac{0.64 \text{ in/hour}}{0.60 \text{ in/hour}} = 1.1$$

$$\frac{f}{I_{10-yr}} = \frac{0.64 \text{ in/hour}}{1.55 \text{ in/hour}} = 0.4$$

$$\frac{f}{I_{100-yr}} = \frac{0.64 \text{ in/hour}}{2.60 \text{ in/hour}} = 0.2$$

Calculations for Sub-basin E include the following:

$$A_R = \frac{RPA}{UIA} = \frac{0.04 \text{ ac}}{0.11 \text{ ac}} = 0.36$$

$$I_{a \text{ Check}} = \frac{1}{1 + A_R} = \frac{1}{1 + 0.36} = 0.73$$

This is mathematically equivalent to UIA/(RPA+UIA) = 0.11/(0.04+0.11).

f/I calculations for Sub-basin E include:

$$\frac{f}{I_{WQ}} = \frac{1.04 \text{ in/hour}}{0.60 \text{ in/hour}} = 1.7$$

$$\frac{f}{I_{10-yr}} = \frac{1.04 \text{ in/hour}}{1.55 \text{ in/hour}} = 0.7$$

$$\frac{f}{I_{100-yr}} = \frac{1.04 \text{ in/hour}}{2.60 \text{ in/hour}} = 0.4$$

IRF (K) and Effective Impervious Calculations

The next set of calculations determines the Impervious Reduction Factors (K values) for each design event and the effective imperviousness of the overall sub-basins.

Note: In the spreadsheet, the abbreviation "IRF" is used interchangeably with "K."

Calculation of the K value is based on a lookup table in the spreadsheet containing the data used to create Figures 3-5 and 3-6.

For the example, Sub-basin A is designated as "V-12" (volume-based BMP with a 12-hour drain time) and Sub-basin E is designated as "C" (conveyance-based). Calculations for IRF and effective imperviousness parameters provided below are shown in Figure 3-10.

Calculations for **Sub-basin A** include the following:

$\text{IRF}_{WQ} = 0.00$

$\text{IRF}_{10-yr} = 0.92$

$\text{IRF}_{100-yr} = 0.96$

The results from the lookup table can be compared against Figure 3-6 (volume-based curves) as a check. The K values can be read off Figure 3-6 using UIA/(RPA + UIA) = 0.56 (56%) and f/I = 1.1, 0.4 and 0.2 for the water quality, 10- and 100-year events respectively. Figure 3-11 illustrates the readings from the volume-based figure.

Calculations for **Sub-basin E** include the following:

$\text{IRF}_{WQ} = 0.77$

$\text{IRF}_{10-yr} = 0.90$

$\text{IRF}_{100-yr} = 0.94$

The results from the lookup table can be compared against Figure 3-5 (conveyance-based curves). The IRF values can be read off Figure 3-5 using UIA/(RPA + UIA) = 0.73 (73%) and f/I = 1.7, 0.7 and 0.4 for the water quality, 10- and 100-year events respectively. Figure 3-12 illustrates the readings from the conveyance-based figure.

The next step, illustrated in Figure 3-10, is to calculate the effective imperviousness for the water quality, 10- and 100-year events for the entire sub-basin. Note that the K value is only applied to the UIA and RPA portions of the sub-basins.

Calculations for **Sub-basin A** include the following:

$$I_{Total} = \frac{DCIA + UIA}{Total\ Area} = \frac{0.00\ ac + 0.56\ ac}{1.15\ ac} = 49\%$$

$$I_{WQ} = 0$$

Note: Because the "V" option was selected in the spreadsheet, the effective imperviousness is set to 0.0 for the WQ event/WQCV (i.e., if the full WQCV is provided by a BMP and an event with less precipitation and runoff than the water quality design event occurs, the BMP will completely treat the runoff from the event, either infiltrating or releasing the runoff in a controlled manner, effectively making the imperviousness of the area on the timescale of the event approximately zero). **In order for I_{WQ} to be set to 0.0 for the water quality event, the full WQCV must be provided for the entire sub-basin**.

$$I_{10-yr} = \frac{IRF_{10-yr} \cdot UIA + DCIA}{Total\ Area} = \frac{0.92 \cdot 0.56\ ac + 0.00\ ac}{1.15\ ac} = 45\%$$

$$I_{100-yr} = \frac{IRF_{100-yr} \cdot UIA + DCIA}{Total\ Area} = \frac{0.96 \cdot 0.56\ ac + 0.00\ ac}{1.15\ ac} = 47\%$$

Calculations for **Sub-basin E** include the following:

$$I_{Total} = \frac{DCIA + UIA}{Total\ Area} = \frac{0.00\ ac + 0.11\ ac}{0.15\ ac} = 73\%$$

$$I_{WQ} = \frac{IRF_{WQ} \cdot UIA + DCIA}{Total\ Area} = \frac{0.77 \cdot 0.11ac + 0.00\ ac}{0.15\ ac} = 56\%$$

$$I_{10-yr} = \frac{IRF_{10-yr} \cdot UIA + DCIA}{Total\ Area} = \frac{0.90 \cdot 0.11\ ac + 0.00\ ac}{0.15\ ac} = 66\%$$

$$I_{100-yr} = \frac{IRF_{100-yr} \cdot UIA + DCIA}{Total\ Area} = \frac{0.94 \cdot 0.11\ ac + 0.00\ ac}{0.15\ ac} = 69\%$$

Water Quality Capture Volume and 10- and 100-year Detention Volume Adjustments

Once the effective imperviousness values are calculated for the sub-basins, the adjusted, effective imperviousness values can be used in drainage calculations for conveyance and storage to quantify benefits of conveyance- and storage-based BMPs. Spreadsheet calculations are shown in Figure 3-10.

WQCV

To quantify the benefits of disconnected impervious area and other BMPs on the WQCV, the WQCV is calculated using both the total imperviousness and effective imperviousness of each sub-basin.

Calculations for **Sub-basin A** include the following:

$$WQCV\ I_{Total} = \left(0.91 \cdot I_{Total}^3 - 1.19 \cdot I_{Total}^2 + 0.78 \cdot I_{Total}\right) \cdot Total\ Area \cdot \frac{43560\ ft^2}{ac} \cdot \frac{1ft}{12\ in}$$

$$WQCV\ I_{Total} = (0.91 \cdot 0.49^3 - 1.19 \cdot 0.49^2 + 0.78 \cdot 0.49) \cdot 1.15\ ac \cdot \frac{43560\ ft^2}{ac} \cdot \frac{1ft}{12\ in} = 846\ ft^3$$

Since the volume-based option is specified for Sub-basin A, by definition, the entire WQCV (846 ft³) is to

be provided. Therefore, there is no need to calculate WQCV I_{WQ} for Sub-basin A. The spreadsheet returns the result "N/A." The effects of providing the WQCV for Sub-basin A lead to reductions in detention storage requirements for the 10- and 100-year events as demonstrated below.

Calculations for **Sub-basin E** include the following:

$$\text{WQCV } I_{Total} = \left(0.91 \cdot I_{Total}^3 - 1.19 \cdot I_{Total}^2 + 0.78 \cdot I_{Total}\right) \cdot \text{Total Area} \cdot \frac{43560 \text{ ft}^2}{\text{ac}} \cdot \frac{1\text{ft}}{12 \text{ in}}$$

$$\text{WQCV } I_{Total} = (0.91 \cdot 0.73^3 - 1.19 \cdot 0.73^2 + 0.78 \cdot 0.73) \cdot 0.15 \text{ ac} \cdot \frac{43560 \text{ ft}^2}{\text{ac}} \cdot \frac{1\text{ft}}{12 \text{ in}} = 158 \text{ ft}^3$$

Next, the WQCV associated with I_{WQ} is calculated:

$$\text{WQCV } I_{WQ} = \left(0.91 \cdot I_{WQ}^3 - 1.19 \cdot I_{WQ}^2 + 0.78 \cdot I_{WQ}\right) \cdot \text{Total Area} \cdot \frac{43560 \text{ ft}^2}{\text{ac}} \cdot \frac{1\text{ft}}{12 \text{ in}}$$

$$\text{WQCV } I_{WQ} = (0.91 \cdot 0.56^3 - 1.19 \cdot 0.56^2 + 0.78 \cdot 0.56) \cdot 0.15 \text{ ac} \cdot \frac{43560 \text{ ft}^2}{\text{ac}} \cdot \frac{1\text{ft}}{12 \text{ in}} = 122 \text{ ft}^3$$

Therefore, the reduction in the required WQCV from the implementation of conveyance-based BMPs in Sub-basin E is approximately 158 ft³ – 122 ft³ = 36 ft³, or approximately 23% relative to the WQCV based on total imperviousness.

10-Year Event

To evaluate effects of conveyance- and volume-based BMPs on 10-year detention storage volumes, the empirical equations from the *Storage* chapter of Volume 1 can be applied to the total impervious area and the effective imperviousness. The results of these calculations can be compared to determine the associated 10-year volume reduction.

Calculations for **Sub-basin A** include the following:

$$V_{10} \, I_{Total} = \frac{(0.95 \cdot I_{Total} - 1.90)}{1000} \cdot \text{Total Area} \cdot 43560 \, \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{10} \, I_{Total} = \frac{(0.95 \cdot 49\% - 1.90)}{1000} \cdot 1.15 \text{ ac} \cdot 43560 \, \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}} = 2222 \text{ ft}^3$$

The same calculation is then performed using the effective imperviousness for the 10-year event:

$$V_{10} \, I_{10-yr \, Effective} = \frac{\left(0.95 \cdot I_{10-yr \, Effective} - 1.90\right)}{1000} \cdot \text{Total Area} \cdot 43560 \, \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{10} \, I_{Total} = \frac{(0.95 \cdot 45\% - 1.90)}{1000} \cdot 1.15 \text{ ac} \cdot 43560 \, \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}} = 2046 \text{ ft}^3$$

The reduction in the 10-year storage volume as a result of the conveyance-based BMPs in Sub-basin A is, therefore, 2222 ft³ – 2046 ft³ = 176 ft³, or approximately 8% relative to the 10-year storage volume based on total imperviousness.

Calculations for **Sub-basin E** include the following:

$$V_{10}\, I_{Total} = \frac{(0.95 \cdot I_{Total} - 1.90)}{1000} \cdot \text{Total Area} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{10}\, I_{Total} = \frac{(0.95 \cdot 73\% - 1.90)}{1000} \cdot 0.15\ \text{ac} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}} = 443\ \text{ft}^3$$

The same calculation is then performed using the effective imperviousness for the 10-year event:

$$V_{10}\, I_{10-yr\ Effective} = \frac{\left(0.95 \cdot I_{10-yr\ Effective} - 1.90\right)}{1000} \cdot \text{Total Area} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{10}\, I_{10-yr\ Effective} = \frac{(0.95 \cdot 66\% - 1.90)}{1000} \cdot 0.15\ \text{ac} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}} = 395\ \text{ft}^3$$

The reduction in the 10-year storage volume as a result of the conveyance-based BMPs in Sub-basin E is, therefore, 443 ft^3 – 395 ft^3 = 48 ft^3, or approximately 11% relative to the 10-year storage volume based on total imperviousness.

100-Year Event

To evaluate effects of conveyance- and volume-based BMPs on 100-year detention storage volumes, the empirical equations from the *Storage* chapter of Volume 1 can be applied to the total impervious area and the effective imperviousness. The results of these calculations can be compared to determine the associated 100-year volume reduction. Please note that there are two empirical equations for the 100-year detention storage volume in the *Storage* chapter, one for HSG A soils and the other for HSG B, C and D soils. The spreadsheet selects the appropriate equation based on the RPA infiltration rate that is input for the sub-basin. If the RPA infiltration rate is greater than or equal to 1 inch/hour, the HSG A equation is used. Otherwise, the HSG B, C and D equation is used.

Calculations for **Sub-basin A** include the following:

$$V_{100}\, I_{Total} = \frac{\left(-0.00005501 \cdot I_{Total}^2 + 0.030148 \cdot I_{Total} - 0.12\right)}{12} \cdot \text{Total Area} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{100}\, I_{Total} = \frac{(-0.00005501 \cdot 49\%^2 + 0.030148 \cdot 49\% - 0.12)}{12} \cdot 1.15\ \text{ac} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$
$$= 5083\ ft^3$$

The same calculation is then performed using the effective imperviousness for the 100-year event:

$$V_{100}\, I_{100-yr\ Effective}$$
$$= \frac{\left(-0.00005501 \cdot I_{100-yr\ Effective}^2 + 0.030148 \cdot I_{100-yr\ Effective} - 0.12\right)}{12}$$
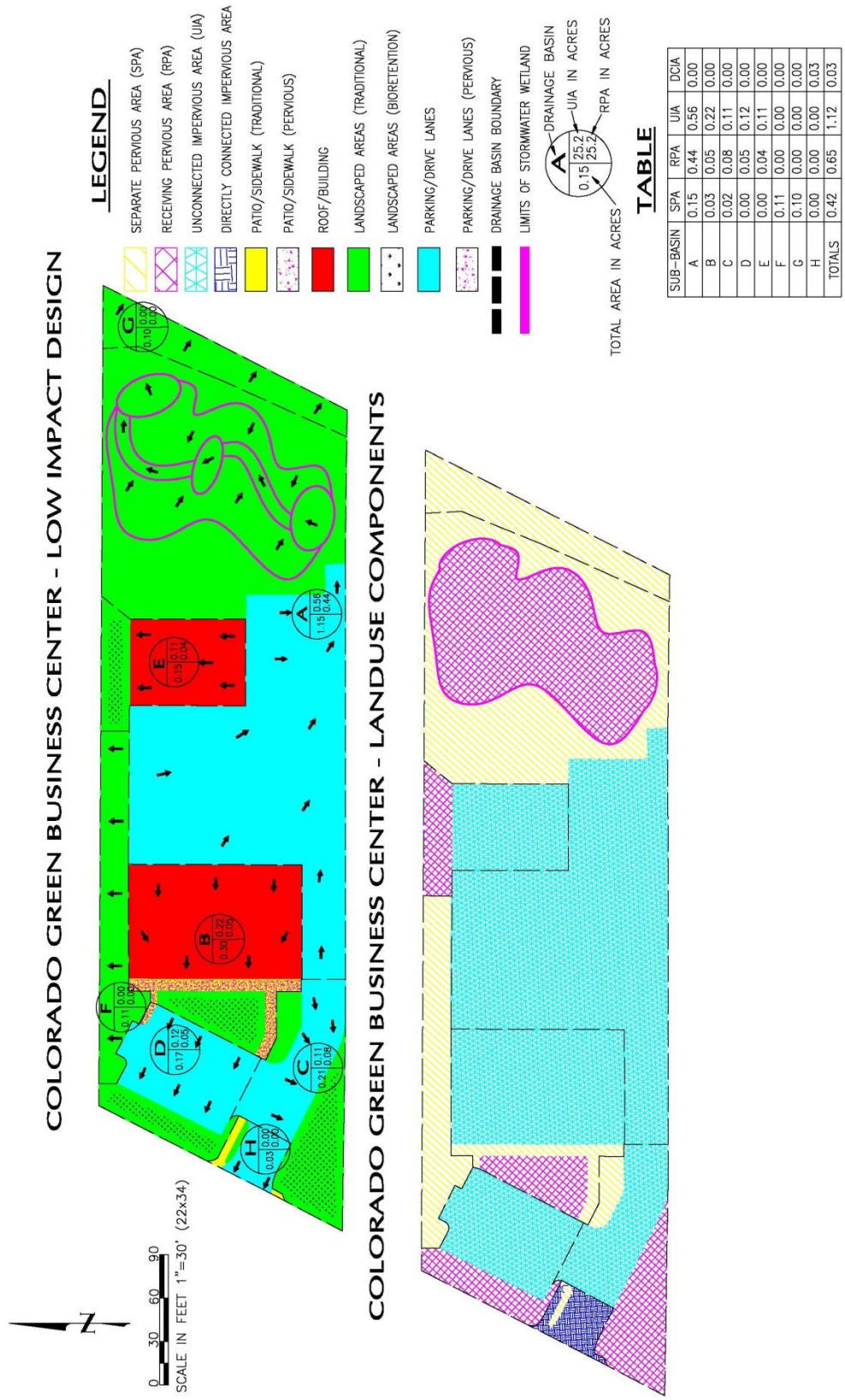$$\cdot \text{Total Area} \cdot 43560\ \frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{100}\,I_{100-yr\,Effective} = \frac{(-0.00005501 \cdot 47\%^2 + 0.030148 \cdot 47\% - 0.12)}{12} \cdot 1.15\,\text{ac} \cdot 43560\,\frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$
$$= 4865\,\text{ft}^3$$

The reduction in the 100-year storage volume, as a result of the conveyance-based BMPs in Sub-basin A, is 5083 ft^3 – 4865 ft^3 = 218 ft^3, a reduction of approximately 4.3%.

Calculations for **Sub-basin E** include the following:

$$V_{100}\,I_{Total} = \frac{\left(-0.00005501 \cdot I_{Total}^2 + 0.030148 \cdot I_{Total} - 0.12\right)}{12} \cdot \text{Total Area} \cdot 43560\,\frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{100}\,I_{Total} = \frac{(-0.00005501 \cdot 73\%^2 + 0.030148 \cdot 73\% - 0.12)}{12} \cdot 0.15\,\text{ac} \cdot 43560\,\frac{\text{ft}^3}{\text{ac} \cdot \text{ft}} = 977\,\text{ft}^3$$

The same calculation is then performed using the effective imperviousness for the 100-year event:

$$V_{100}\,I_{100-yr\,Effective}$$
$$= \frac{\left(-0.00005501 \cdot I_{100-yr\,Effective}^2 + 0.030148 \cdot I_{100-yr\,Effective} - 0.12\right)}{12}$$
$$\cdot \text{Total Area} \cdot 43560\,\frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$

$$V_{100}\,I_{100-yr\,Effective} = \frac{(-0.00005501 \cdot 69\%^2 + 0.030148 \cdot 69\% - 0.12)}{12} \cdot 0.15\,\text{ac} \cdot 43560\,\frac{\text{ft}^3}{\text{ac} \cdot \text{ft}}$$
$$= 927\,\text{ft}^3$$

The reduction in the 100-year storage volume as a result of the volume-based BMPs in Sub-basin E is, therefore, 977ft^3 – 927 ft^3 = 50 ft^3, a reduction of approximately 5%.

6.0   Conclusion

This chapter provides the computational procedures necessary to calculate the WQCV and adjust imperviousness values used in these calculations due to implementation of LID/MDCIA in the tributary watershed. The resulting WQCV can then be combined with BMP specific design criteria in Chapter 4 to complete the BMP design(s). Adjustments to imperviousness and Curve Numbers resulting from these procedures can be used as input into methods for estimating runoff described in the *Hydrology* chapter of Volume 1 and for sizing storage volumes described in the *Storage* chapter of Volume 1.

LEGEND

	SEPARATE PERVIOUS AREA (SPA)
	RECEIVING PERVIOUS AREA (RPA)
	UNCONNECTED IMPERVIOUS AREA (UIA)
	DIRECTLY CONNECTED IMPERVIOUS AREA
	PATIO/SIDEWALK (TRADITIONAL)
	PATIO/SIDEWALK (PERVIOUS)
	ROOF/BUILDING
	LANDSCAPED AREAS (TRADITIONAL)
	LANDSCAPED AREAS (BIORETENTION)
	PARKING/DRIVE LANES
	PARKING/DRIVE LANES (PERVIOUS)
	DRAINAGE BASIN BOUNDARY
	LIMITS OF STORMWATER WETLAND

TABLE

SUB-BASIN	SPA	RPA	UIA	DCIA
A	0.15	0.44	0.56	0.00
B	0.03	0.05	0.22	0.00
C	0.02	0.08	0.11	0.00
D	0.00	0.05	0.12	0.00
E	0.00	0.04	0.11	0.00
F	0.11	0.00	0.00	0.00
G	0.10	0.00	0.00	0.00
H	0.00	0.00	0.00	0.03
TOTALS	0.42	0.65	1.12	0.03

Figure 3-7. Colorado Green Development DCIA, UIA, RPA, and SPA

Figure 3-8. Colorado Green Precipitation Input Screen Shot

Figure 3-9. Colorado Green Area and Infiltration Input Screen Shot

Figure 3-10. Colorado Green Calculated Output Screen Shot
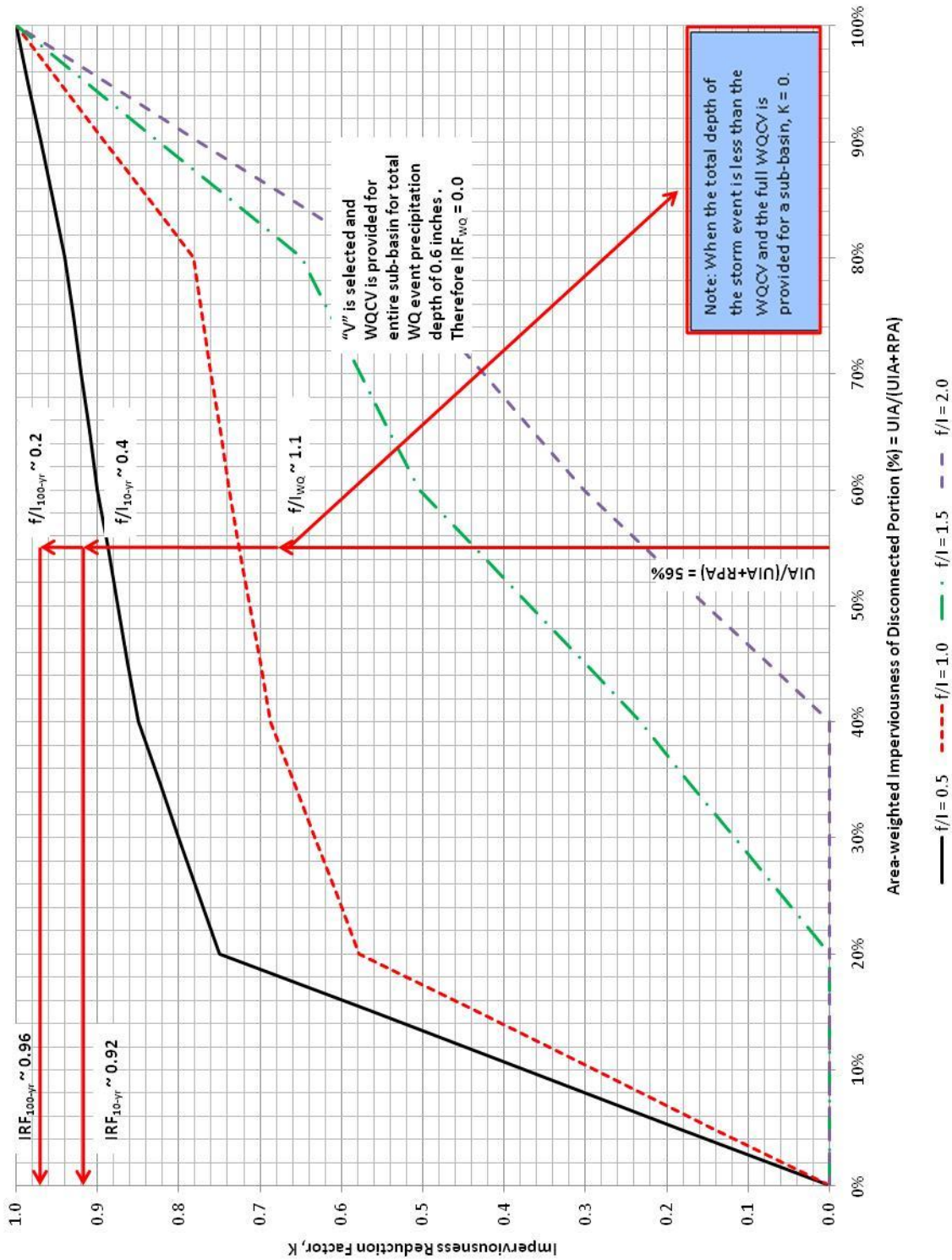
Figure 3-11. Colorado Green Imperviousness Reduction Factor Volume-based Lookup (Sub-basin A)
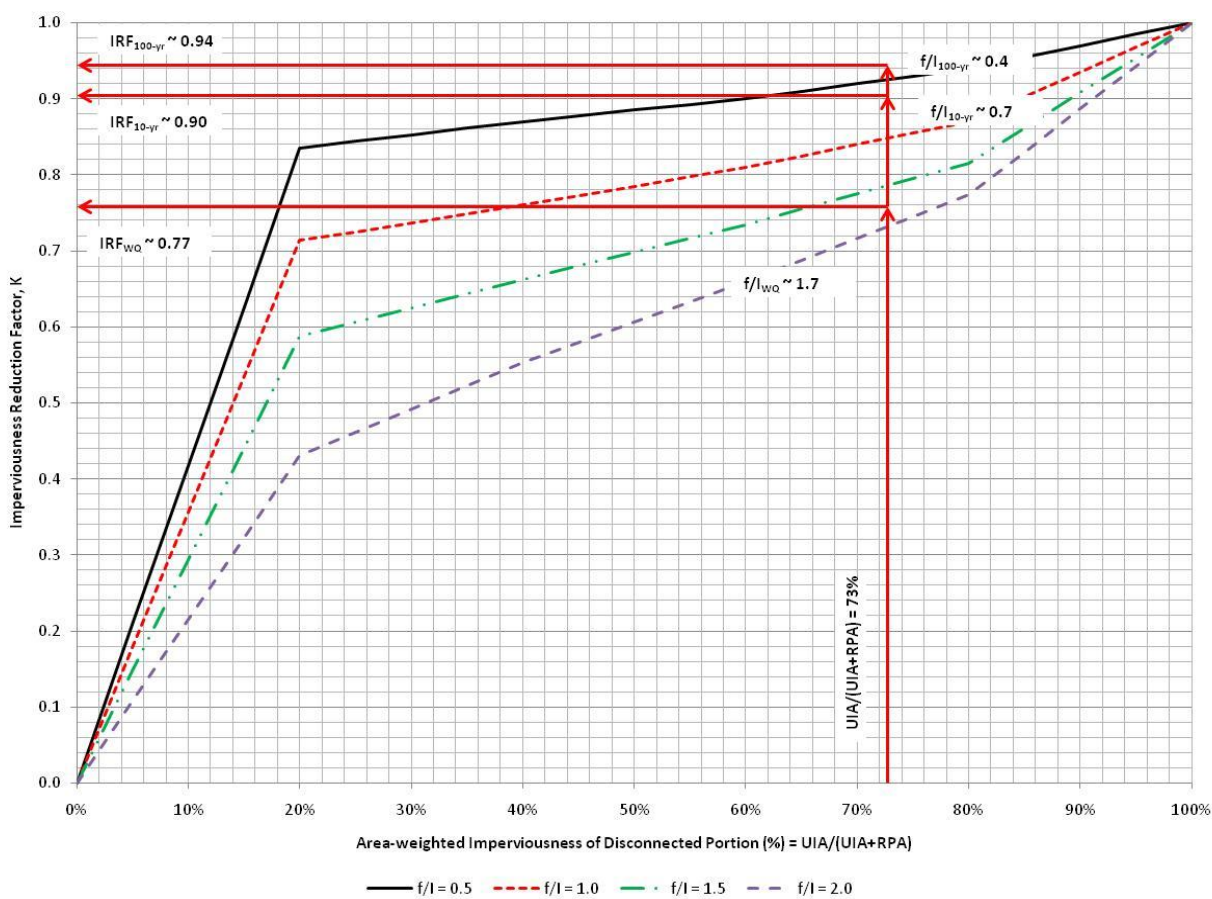
**Figure 3-12. Colorado Green IRF Conveyance-based Lookup
(Sub basin E)**

7.0   References

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